RENEWABLE FUEL GRATE FIRING COMBUSTION TECHNOLOGY – THE EUROPEAN EXPERIENCE

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INTRODUCTION

World wide regulations concerning new or modified combustion systems are continuing to be more stringent. Fueled by concerns of global warming and green house gases; the use of renewable, agricultural and opportunity fuels has increased rapidly. In 1947, Detroit Stoker Company first developed a grate system specific for woodchip/bark firing. Since then more than 200 systems for biomass combustion have been designed, installed and operated worldwide. In 1994, Detroit Stoker Company provided its first grate combustion system into the European market specifically based on the more stringent demands of emissions, availability and fuel quality than previously encountered in the North American market. This equipment utilizes the technology of spreader firing with continuous ash discharge grates, which were a departure from the more common mass fed and fluid bed technologies primarily used in Europe. Since 1994, Detroit Stoker Company has successfully provided a total of eighteen (18) systems into the European market firing a wide variety of renewable fuels.

FUELS

The majority of the European systems have been for firing of recycled wood products, primarily from demolished buildings (urban waste). Other wood products, such as railroad ties, tree/bush trimmings and cuttings are included along with local waste streams generated by forest products manufactures (sawdust/sander dust). Owners and operators include both local utilities and industrial manufactures. A handful of these installations utilize a percentage of agricultural wastes including remnants of olive pulp left over from production of olive oil. Two (2) of these facilities specifically fire chicken/turkey litter. Table A indicates the typical North American fuel analysis as compared with the typical European fuel analysis.

TABLE A

Analysis	North America	Europe
Type	Bark & Chips	Demolition & Waste wood
HHV (Btu/lb)	3900-4500	5100-7400
H_2O (%)	45 - $^{+}$55	12 - 40
Ash (%)	2-5	3 - 15
C (%)	26	25
H (%)	2.5	2.5
O (%)	19	18
N (%)	0.05	0.5 - 1.0
S (%)	0.05	0.05
Cl (%)	Trace	0.5 - 1.0
Metal (%)	1.0	+3
K_2O (%)	3.0 - 6.0	8 - 18
Na_2O (%)	<1.0	1 - 4

Due to the ranges of the fuel constituents for the European fuel(s), care must be taken with both grate and boiler performance. Increased metal content can cause decreased availability of equipment. Higher alkali content can greatly increase slagging and fouling occurrences and higher fuel nitrogen contents can lead to greater variability in NOx emissions. These and other considerations influence both the furnace construction and grate selection.

BOILER COMPARISIONS

There are differences with the boilers in North America and those being constructed in Europe. One notable physical difference is that most North American boilers have two drums while the European has a single drum, folded boiler arrangement. Figures 1 and 2 illustrate these differences respectively.

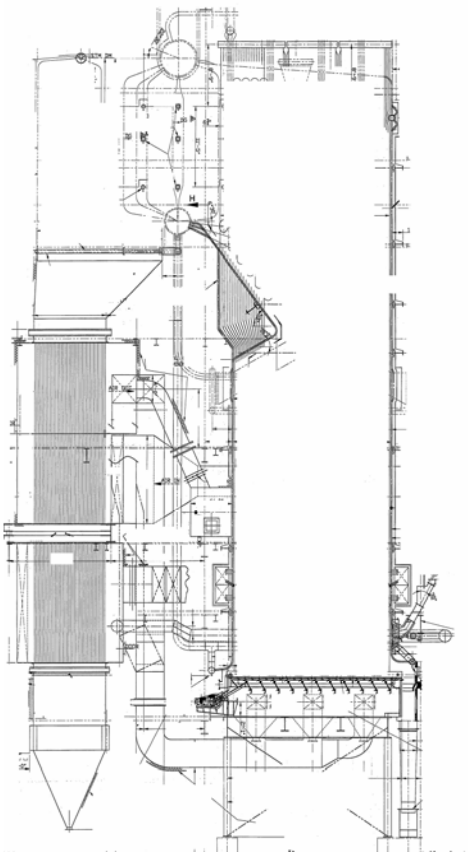

Figure 1- Typ. North American Arrgt

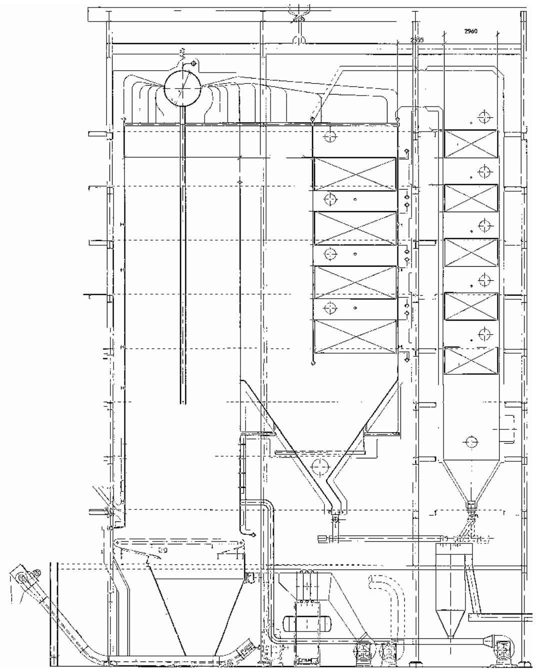

Figure 2 – Typ. European Arrgt

Table B provides additional comparative differences between European and North American boiler designs.

TABLE B

Value	North America	Europe
Steam Capacity (Klbs/hr)	250-500	100-200
Grate heat release rates (KBtu/ft^2/hr)	1,000	850
Volumetric heat release rates (KBtu/ft^3/hr)	18-22	12-14
Furnace Residence Time (Seconds)	1.8	3.0
Pre-heated air supply	Tubular or regenerative	Steam Coil
Air Pollution Control	Precipitator	Bag House

When evaluating these differences we consider that the North American boiler design application was primarily for the pulp and paper industry, which requires a high capacity of process steam. In the past, these boilers were easily permitted with little or no emission requirements other than opacity. Until the last decade, the fuel was generated from the mill process areas and provided a constant source of consistent and good quality biomass. The European boiler projects have limited self-generated fuel. Therefore the fuel must be delivered to the plant site. Due to the expensive transportation costs in Europe, the radius from which the fuel is taken from is restricted. This results in a smaller capacity size of these power plants, particularly in the case of utility owned plants where no process steam is required and the optimum size for electrical generation is 15-20 MW_e. As a result, the fuel stream is extremely important and the plant design has to account for not only seasonal fuels, but extreme variability of fuels from multiple sources on a daily basis. In addition to fuel quality, consideration has to be made regarding the strict regulations for emissions, particularly Carbon Monoxide (CO) limits which are extensively less than current North American permit values. Steam coil pre-heaters for the primary air system are extensively used and provide an additional tool for the boiler's operation due to varying fuel moistures and consistency.

EMISSION REGULATIONS

The European regulations for overall performance and emission standards are, for the most part, more stringent than those found in North America. There are several reasons for this including agreement with the Kyoto Treaty for reduction of green house gases and the formation of the European Union, which continues to emphasize common rules/regulations. A large portion of the European renewable fuels are a demolition (urban) fuel type that has ferrous / non-ferrous metals and other contaminates in the fuel source. Regulations for these facilities are often similar to those North American facilities used for Municipal Solid Waste (MSW) combustion. It is not uncommon to have regulations in Europe where VOC and Dioxin limits are set and that the owners must demonstrate that fuel/ash particles must obtain a temperature of 1562 ºF (850 ºC) for a minimum of 2 seconds. NOx values are not particularly stringent as compared to North American requirements, but as a matter of practice nearly all facilities are equipped with a Selective Non-Catalytic Reagent (SNCR).

European regulations also evaluate carbon loss and promote regulations to minimize total fly ash. This is primarily done by having different classifications according to the amount of unburned carbon and metal(s) content. As the fly ash content of either increases, the disposal method and therefore costs increase dramatically. With these constraints, nearly all of these facilities have incorporated fly carbon re-injection for reduction of total land filled fly ash. Table C compares the more commonly accepted emissions limitations for North America and Europe. Obviously, there are facilities both in North America and Europe which might have more or less stringent limitations then noted, but the values represented indicate those values most commonly seen

TABLE C
Emission Requirement Comparison

Value	North America	Europe
NOx – Controlled (lbs/MMBtu)	0.15 - 0.25	0.16 - 0.25
Carbon Monoxide (lbs/MMBTU)	0.25 - 0.40	0.06 - 0.12
VOC (lbs/MMBtu)	0.02 - 0.05	0.012
Total Unburned Carbon Loss (%)	3-5	≤ 2

FURNANCE COMBUSTION TECHNOLOGIES
This paper focuses on spreader stoker combustion technology; however, other competing technologies are presented as a comparison.

MASS FIRED GRATE
Mass fired grates typically used today are a step type grate, mass fed from a chute in the front of the boiler, as shown in Figure 3.

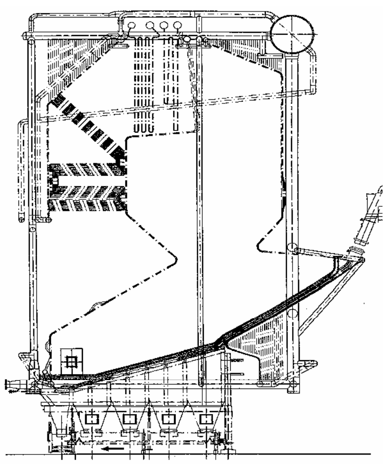

Figure 3 – Typ. Mass Fired Grate

Mass fired grates are designed either water or air-cooled. The first section typically is an inclined water-cooled stationary grate used to drive off moisture in the fuel. These grates are good for steady constant loads, since the response time is slow, but would not fit well for applications where load swings readily occur. In general these types of grates require large grate areas and depending on fuel and configuration exhibit high wear.

FLUIDIZED BED
Bubbling Fluidized Bed (BFB) boilers are typically used when firing biomass. The firing mode is similar to spreader fired stoker technology where the fuel is spread into the furnace over the bed. The bed in this case is made up of sand with a series of high-pressure nozzles below which fluidizes the bed. The fluidized sand bed mixes with the fuel to complete its combustion. Since the sand bed mixes with the fuel, higher moistures in the range of 65% can be fired. There are limitations however when the fuel becomes dryer and calorific values increase. For example, opportunity fuels such as Tire Derived Fuel (TDF) will be more restricted on a fluidized bed due to maximum bed temperature limitations. Fluid beds often exhibit extensive wear to bed components such as tuyere nozzles and higher operating costs due to higher operating pressures.

SPREADER FIRED STOKER
Spreader fired stoker technology has been used for more than 60 years and continues to serve today's market. Currently three types of spreader fired stokers are utilized in the Pulp and Paper Industry, Independent Power Producers, as well as Forest Product industries in North America and abroad. Those used in Europe have primarily been the air-cooled traveling grate (RotoGrate) and the water-cooled vibrating grate (Hydrograte).

The *Air-Cooled Traveling Grate Stoker,* shown in Figure 4, has been used in more industries and has fired a wider variety of fuels than most other firing systems. It has fired high and low quality coal, bark, bagasse, chicken litter, RDF (Refuse Derived Fuel) and MBM (Meat & Bone Meal). The fuel is introduced to the furnace with air swept fuel distributors to the rear of the grate. The larger particles land on the grate surface and the smaller particles are very quickly burned in suspension.
The continuous ash discharge grate moves the fuel/ash bed forward discharging ash at the front. Siftings or riddlings fall through the grate, into a plenum hopper, and discharged by conventional means.

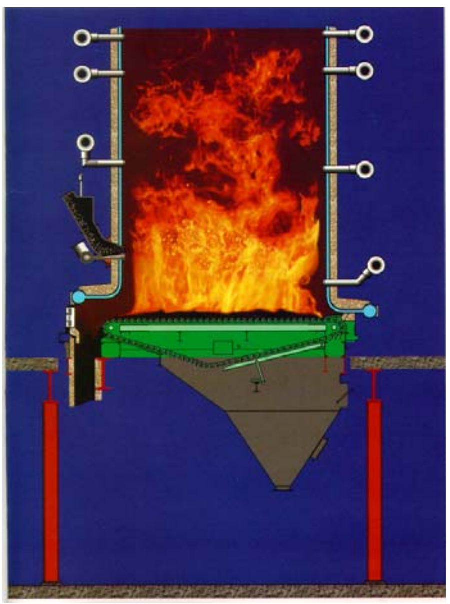

Figure 4 – Air-Cooled Travel Grate

The next type of spreader fired stoker is the *Air-Cooled Vibrating Conveying Grate Stoker* shown in Figure 5. Its initial use was to fire coal in coal drying applications, however today it is used primarily to fire biomass and particularly popular for boiler conversions.

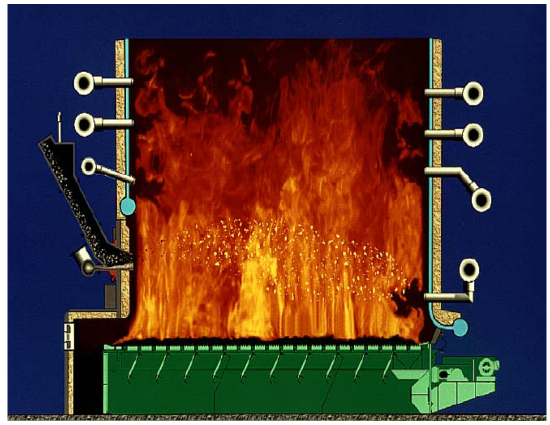

Figure 5 – Air-Cooled Vibrating Grate

It operates similarly to the Traveling Grate Stoker, but instead of a continuous ash discharge, it utilizes an intermittent ash removal system where the grate surface vibrates at low amplitudes for approximately 2% of the time to move the bed forward to discharge the ash off the front. This type of grate uses very few moving parts and the drive mechanism is external to the heat, which increases grate life and reduces maintenance costs, resulting in high equipment availability.

The third type of spreader fired stoker is the *Water-Cooled Vibrating Conveying Grate Stoker* as shown in Figure 6 below.

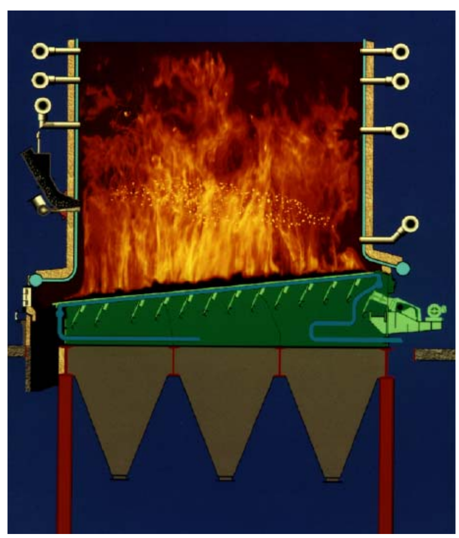

Figure 6 – Water-Cooled Vibrating Grate

Its operation is similar to the Air-Cooled Vibrating Conveying Grate, but it includes water-cooled tubing beneath the grate surface. This tubing circulates dearated water through a multipass grid that maintains the grate surface at a relatively low temperature resulting in extended grate life. Since it requires very little air to keep the grate surface cool, primary air flow is set for combustion requirements and therefore is a very flexible firing tool when used in conjunction with the more advanced secondary air systems.

The cooled surface can fire a wide range of fuels and fuel moistures, ranging from low moistures of 10% up to higher moistures of 60%. Opportunity fuels such as TDF can be fired at higher percentages than the BFB and air-cooled stokers.

Table D, shows a comparison of the Mass Fired, Fluidized Bed, and Spreader Fired Stokers. Developers, Consultants and Owners need to review these options to evaluate and choose the system that is overall best suited for their specific application.

TABLE D

	Mass Fired Stoker	**Fluidized Bed**	**Spreader Stoker**
Maximum Moisture	65	65	60
Response Time	Slow	Good	Good
Release Rate	~350 KBtu/hr	+900 KBtu/hr	+900 KBtu/hr
Emission	Good	Good	Good
Capital Cost	Medium	High	Medium to Low
Oper. & Main. Costs	High	High	Medium (traveling) Very Low (Vibrating)
Availability	Medium	Medium	High

GERMAN RENEWABLE FUEL FACILITY

In the fall of 2003, Detroit Stoker Company commissioned a 20 MW_e renewable energy, air-cooled traveling grate combustion system in Germany. This facility utilizes a combination of urban waste, natural wood waste and agricultural waste having combined fuel moisture content between 35-40%. This facility was permitted with higher values of CO and NOx requirements than that seen at other facilities.

This was in part due to the nature of the fuel(s), particularly the urban waste as it was considered to have more contaminates than the typical urban waste. As a result, the regulators determined that considerations of incineration and reduction of ash disposal take a higher priority as compared to the gaseous emissions.

As part of the contract, Detroit Stoker Company was commissioned to provide a Computational Fluid Dynamics (CFD) model of the lower furnace combustion, specifically to determine if the design for the boiler, grate, secondary/primary air were capable of meeting required CO values and more importantly if all particles would obtain 1562 ºF (850 ºC) for a minimum of 2 seconds for the design composite fuel. Figure 7 illustrates the boundary mesh of the CFD simulation.

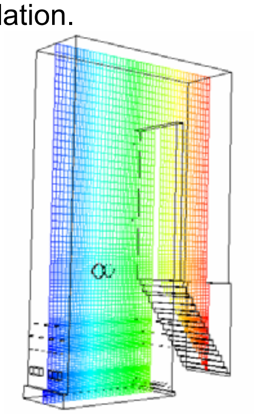

Figure 7-CFD Boundary Mesh

Initial results of the CFD modeling indicated that the time/temperature requirements were marginal (Figure 8). Closer analysis of the fuels to be utilized was performed, particularly in regards to particle sizing.

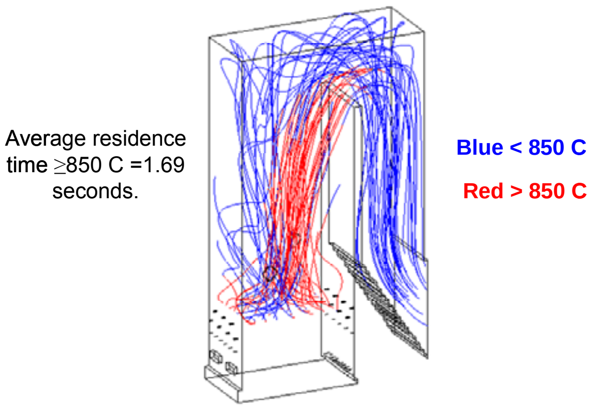

Figure 8 – Initial Results

Results indicated that the composite fuel sizing was not within the range of the contract fuel specification. Further work performed by Detroit Stoker Company using both in-house computer simulations and full scale distribution testing (Figures 9 and 10 respective), provided additional information regarding fuel distribution and better characterization of the combustion process.

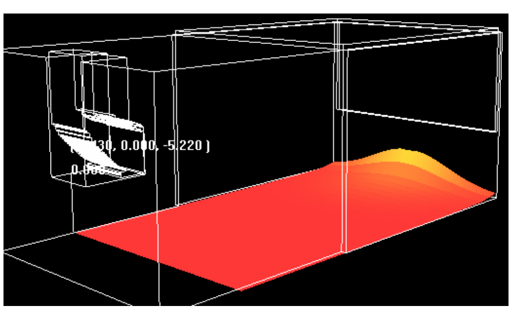

Figure 9 – Fuel Distribution Simulation

Figure 10 – Physical Distribution Test

Refinements to better simulate the actual fuel, combustion characteristics and adjustments to the combustion air settings provided new results which would be much more indicative to actual operating experiences. Figure 11 illustrates the improved time/ temperature relationship.

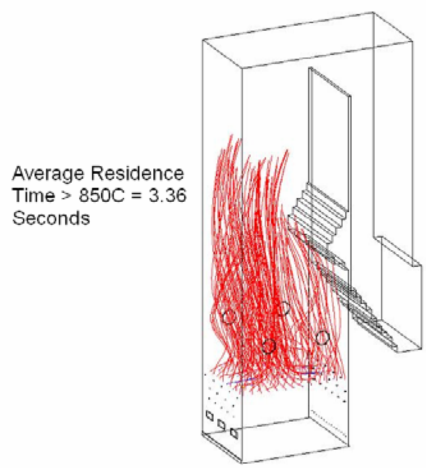

Figure 11 – Revised CFD Results

Included with this CFD study were comparative trends of furnace temperatures, CO concentrations and Oxygen concentrations.

Table E, provides a summary of the corresponding results of this CFD study and actual commissioning data for the installation.

TABLE E

Comparative Performance Data

Value	1st CFD	2nd CFD	Actual Data	Permit Level
CO (lbs/MMBtu)	0.037	0.024	0.050	0.183 Max.
Exit gas Temp. (F)	1257	1308	1356	N/A
Particle Residence Time (Sec.)	1.6	3.3	2.8	2.0 Min.
NOx (lbs/MMBtu)	N/F	N/F	0.366	0.488 Max.

OPPORTUNITY FUELS

For over 40 years, a variety of spreader fired facilities have supplemented their main fuel with a different fuel type. When discussing renewable fired facilities, the major choices have been oil, natural gas and coal. For the majority of cases these auxiliary fuels have been for reduction of fuel costs, reliable fuel(s) availability and for a few facilities emission reduction. In the past decade, these previously used fuels no longer have a cost advantage, as with the main renewable fuel source. As a result, fuels generally considered waste are now a commodity and both current and future owners/operators are looking at the ability to supplement their main fuel with low cost fuels that have been generally considered wastes. Examples include the urban wastes, agricultural, tire derived fuel (TDF), pelletized wastes and process wastes such as sludge, sander and saw dusts.

One such example is a German forest products manufacture, which Detroit Stoker Company originally designed and supplied the combustion system for in 1997.

This facility is a combined heat and power (CHP) facility generating 16 MW_e from a high pressure steam turbine and process steam for the production areas. The fuel is a composition of railroad ties and urban/demolition waste. In addition to the main fuel, this facility also injects sander dust into the furnace.

The dust is from a finishing process and as a result contained glues and resins, used to manufacture the final product. The dust has high nitrogen content (4-7%) and low moisture (5%). The amount of dust injected is 10-20% of the total fuel input required. Since the process dust collection system was existing; the system was extended to the powerhouse and is pneumatically injected into the furnace at multiple points. Because the dust is injected in a high oxygen zone of the furnace and by using low oxygen flue gas as the conveying medium, the injection region is set-up for a reburning type system. As a result, the dust burning capabilities of this facility not only disposes of a high nitrogen waste material, but also has advantages for NOx reduction. Figure 12, illustrates field data of NOx reduction based on dust input.

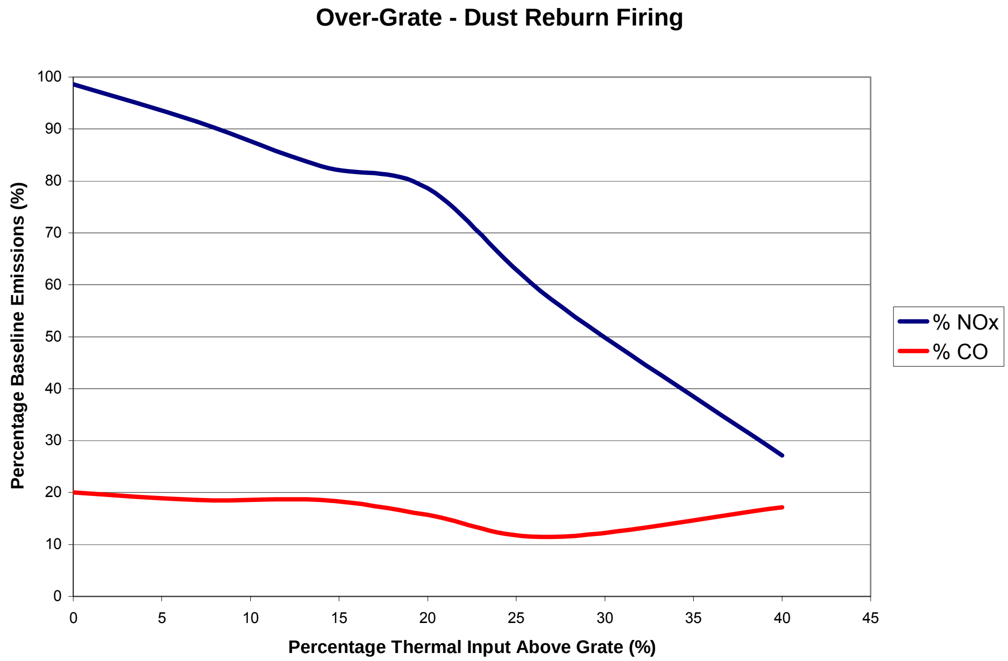

Figure 12** – **Dust Reburn Results

This success with dust reburning has now led to interest in re-injecting recovered fly carbon in the same manner. In fact, there are owners that currently classify recovered char.

Although the resulting material is still being injected in the typical location at the rear wall; it is possible that injection of this low grade carbon could have a positive effect on emission reduction.

CONTINUING EFFORTS

The sources of renewable fuels in Europe have become critical in the past decade. Owners consider their fuel sources proprietary information. Even in North America we are seeing shortages of the more typical renewable fuels. Therefore we can expect to see interest in fuels that have traditionally been ignored.

The use of CFD modeling is useful in determining effectiveness of combustion equipment design. However, this does not always determine effects of a particular fuel.

Figure 13 – Pilot Scale Combustor

To assist with this Detroit Stoker Company, in conjunction with the University of Utah, has constructed a Pilot Scale Combustor (PSC) at the University's Combustion Laboratory. The combustor is a 1.0 MMBtu/hr vibrating grate, spreader stoker, capable of firing a wide variety of biomass, coal and sludges. (Figure 13)

This facility is capable of monitoring virtually all gaseous emissions along with corrosion and fouling conditions. The combustor has capabilities of changing primary and secondary air flows, configuration and temperatures to assist in fuel combustion behavior. The facility continues to be used for in-house studies of various fuels and fuel conditions and has been used by several clients having specific requirements. Figure 14 illustrates comparative data of biomass fuel size and CO production obtained from utilizing the PSC. Information from the PSC and fuel distribution characteristics determined from full scale trials and computer generated results greatly assist in evaluating expected fuel and boiler performance.

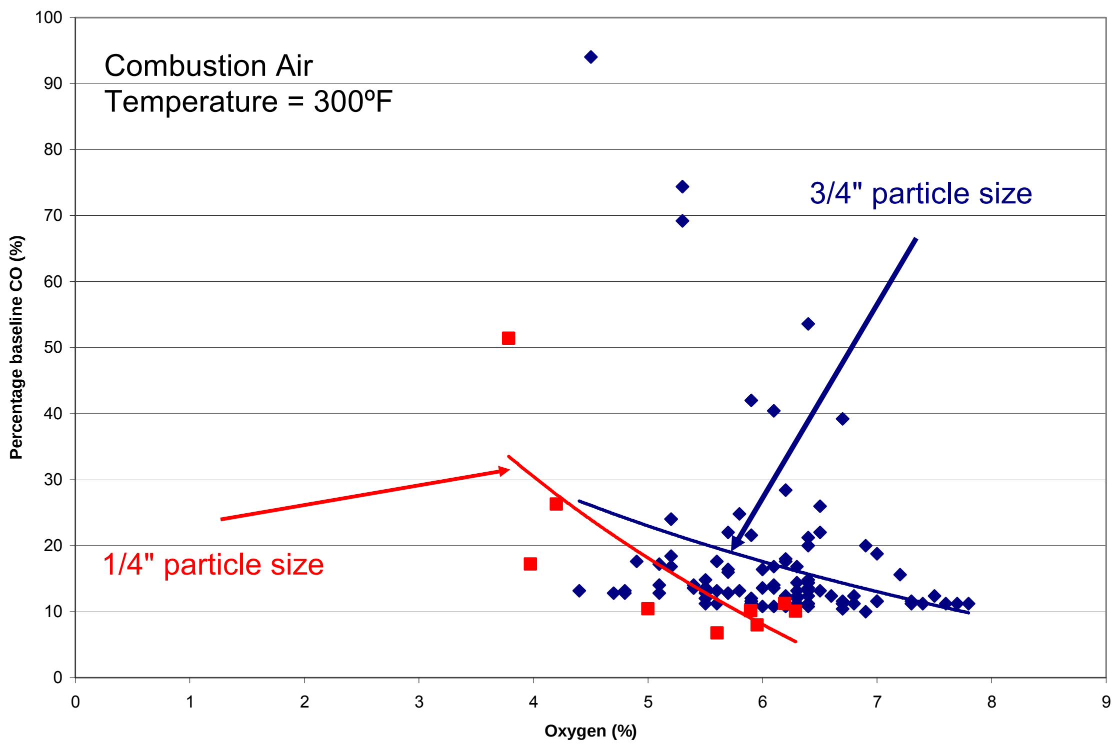

Figure 14 – PSC Results of Fuel Particle size –Vs- CO

Attention must be given to the secondary air systems for all boilers, but is particularly critical with the small European units. The small size and wide range of fuels makes them sensitive to excess air quantities. High excess air rapidly cools the furnace resulting in increased CO and low excess air results in increased CO. The Secondary Air systems need to be designed where the radial and axial velocity of the air in the nozzles matches the furnace velocities for proper mixture. This along with interlacing of the nozzles and multiple levels for flexibility describe most Secondary Air Systems used on biomass boilers today. CFD modeling of the secondary air systems (Reference Figure 15) is used quite extensively today to determine the best nozzle size, spacing and elevation, for new boilers as well as upgrading existing systems. Balancing of the secondary and primary air sources is critical with the urban fuels to minimize alternating zones of reducing and oxidizing atmospheres which create potential lower furnace corrosion issues.

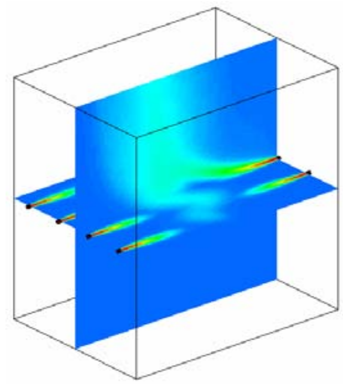

Figure 15 – Secondary Air CFD Results

The spreader fired combustion system still remains a cost effective and technically reliable system for firing a range of solid fuels. Advances in lower furnace design and operational considerations will continue to allow this technology to obtain peak availability and emission performance despite a wide variation in fuels. Continuing development of particle combustion and fuel delivery/distribution systems will further enhance the effectiveness of spreader stoker firing.